The Measurement of Radioactivity At and Below the Ground Surface (Study on Some Phenomena Foretelling the Occurrence of Destructive Earthquakes)

The Measurement of Radioactivity At and Below the Ground Surface

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Abstract

A daily measurement of natural gamma-ray intensity with the Geiger-Müller counter for one year and some special measurements in the deeply seated rooms of the metal mines are described here. An observation of the natural radioactivity of soil and rock with the Lauritsen electroscope is also discussed.

1. Introduction

On December 7, 1944, the great Tōnankai earthquake occurred at a point 20 km offshore in the open sea of Kumano-Nada; there were 3133 casualties and 76,151 buildings were damaged, mainly by a tsunami reaching several meters in height. The epicenter was 136.2°E and 33.7°N, and the seismic magnitude was estimated as more than 8 in the Passadena scale. In this case an abnormal and sudden increase of Radon-intensity was observed in the course of daily measurement by Z. Hatuda [1953], and reported at the Meeting of the Geological Society of Japan in 1945, The Radon-measurement was made at 11 h every day of the air mass collected over a 24 hours-period in the bored hole of about 2 m depth from the ground surface at the Geological Institute of Kyoto University, the epicentral distance being about 150 km. The value measured at 11 h on December 7 showed an abnormal increase of about 20% of the total amount and the earthquake occurred at 13.6 h on the same day. It is an interresting problem as to whether there really exists or not any connection between earthquake-occurrence and the change of soil-radioactivity. But it ought to be mentioned that any trace of a particular change of Radon-intensity was not found in the case of the great Nankaido earthquake of December 21, 1946 whose epicenter (135.7°E, 33.0°N) was near that of the Tōnankai earthquake, and whose seismic magnitude was estimated to be more than 8, the epicentral distance being about 210 km from the observatory. In comparing both cases, the problem of connection between the change of soil-radioactivity with earthquake-occurrence is considered to be very difficult, and depends to a large extent on future research.

* Introduced by Prof. E. Nishimura, member of the Disaster Prevention Research Institute.

On the other hand, many examples on luminous phenomena in connection with the occurrence of destructive earthquakes at night have been recorded over a period of more than one thousand years. And recently, in our country, the detailed data on luminous phenomena accompanying the destructive earthquakes of Kita-Izu (November 26, 1930), Tottori (March 4, 1943), Nankaido (December 21, 1946) and others have been reported. But the nature of the phenomena still remains unsolved, and indeed, the study of these luminous phenomena is the darkest field of research in seismology. The data on these phenomena were greatly disturbed by errors of psychological and illusional origin on the part of the witnesses, as they had all hitherto been obtained by visual observation. It is difficult to observe the phenomena with spectrometric and photometric equipment, but it is considered that they may be suitably observed with instruments for measuring the changes of atmospheric or terrestrial electricity and radioactivity.

Due to the above stated reasons among others, a continuous observation of air- and soil-radioactivity near the epicenter of future destructive earthquakes, the craters of active volcanos and the areas disturbed by crustal deformation was scheduled in 1948 by our Institute. And some preparatory measurements with the Geiger-Müller counter and the Lauritsen electroscope have been made at several places in our country during the past several years. Recently an automatic recording apparatus for the measurement of radioactivity at the deeply seated room was newly designed as a result of the experience gained through past preparatory measurements. It is intended that this apparatus be installed at the adit of a metal mine of several hundreds meters in depth and that the observation results will be reported in the near future. In this paper the apparatus used and the results hitherto obtained in the preparatory measurements of the past several years will be reported and discussed.

2. Apparatus

(a) Geiger Counter (C_a)

The counter was made by the Scientific Research Institute in Tokyo in 1950 and afterwards hermetically reconstructed for the purpose of measurement at deeply seated room of high humidity. The counter is for the measurement of gamma-rays and its counting tube is 1.8 cm in diameter and 10.6 cm in length. A detailed description of its general characteristics and amplifier circuit may be referred to in the paper by T. Sadahiro [1951].

(b) Geiger Counter (C_b)

The counter was made by the Central Scientific Company (Cenco) as a "Radioactivity Demonstrator" in 1951 and afterwards hermetically and

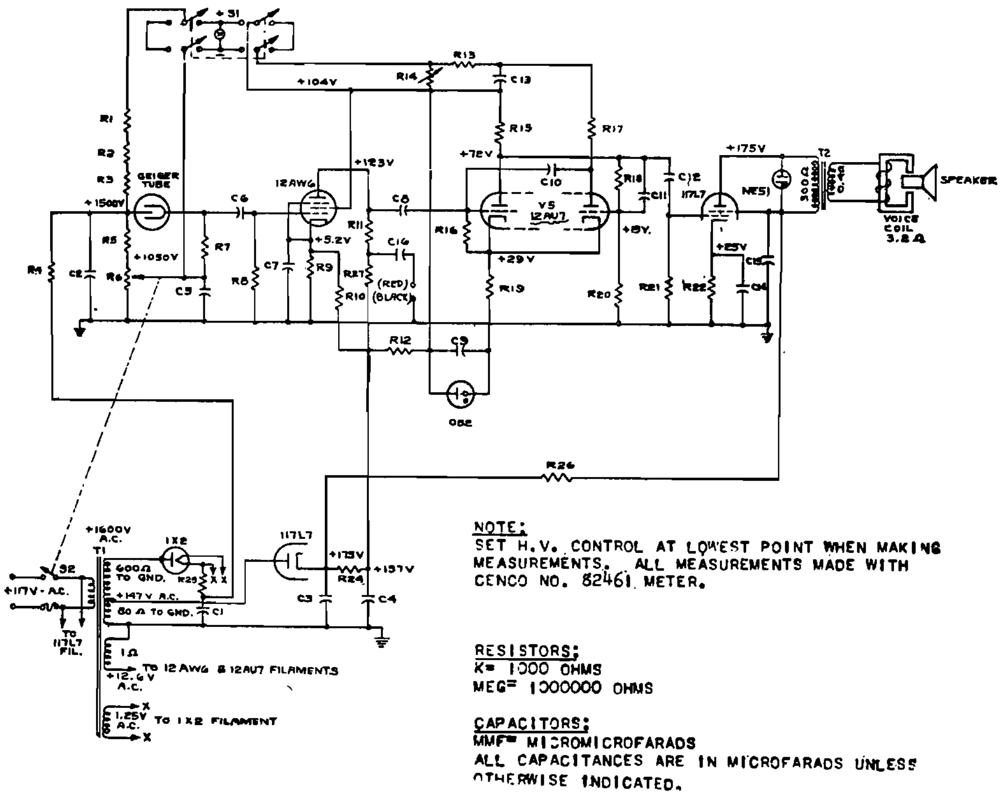

Fig. 1 Electric Circuit of Cb-Counter.

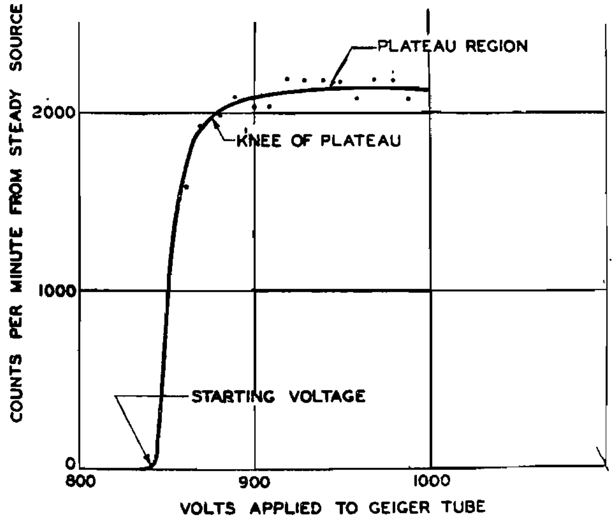

Fig 2

Characteristic curve of Geiger-tube of Cb-Counter.

portably reconstructed. The Geiger tube is a "Tracerlab TGC-5" of about 2 cm in diameter and 10 cm in length. Its electric circuit and Geiger tube characteristics are shown in Figure 1 and 2.

(c) Lauritsen Electrascope (E_a)

The electroscope was made by the Scientific Research Institute in Tokyo in 1950 and afterwards reconstructed as a water-tight apparatus for photograph recording at a deeply seated room of high humidity. ~~The~~ The Lauritsen electroscope is a very sensitive instrument compared with the familiar gold-leaf electroscope, and in this instrument the restoring force is not gravity but an elasticity of a low-capacity by a short, thin, gold-coated quartz fibre. The movement of the fibre is, in usual cases, followed with a microscope, but in the present case it was often used with photographic recording equipment. Its sensitivity is estimated to be 1.64 div./min. by gamma-ray intensity produced by Ra of 1 mc at 1-m distance or 1.00 div./volt in voltage-sensibility.

3. Measurement

(A) Daily Measurement

Gamma-ray intensity was measured daily at the first floor-laboratory of a two-storied brick building at our Geophysical Institute during the period from April, 1952 to January, 1953. The measurement was made with C_a- and C_b-counter during the time between 15 h and 17 h on each day, and the function and sensitivity of the instruments were frequently examined and calibrated by a radioactive source (1 mc of Cobalt-60) at a constant distance. After examination it was ascertained that the function and sensitivity of the C_b-counter was satisfactorily invariable through the whole period of measurement, but the C_a-counter frequently showed irregular changes in its instrumental faculty. Consequently, it was concluded that the C_a-counter is suitable for measurement during a short period (several days), but unsuitable for a long period of observation. In Figure 3 and Table 1 the number of counts per minute (which is the mean value of thirty minutes-counts by the C_b-counter) is plotted for every day from April, 1952 to January, 1953, and their ten days' means are also shown. Below the two intensity curves are drawn for comparison the daily values of atmospheric pressure and temperature at 14 h, and the amounts of rainfall for each 24 hours-period (10 h∼10 h) as observed at the Kyoto Meteorological Observatory, 4 km distant from the Laboratory. The observed variation over a period of several days' or longer in daily gamma-ray intensity were not caused by instrumental or other errors, because the function of the C_b-counter was ascertained to be undisturbed through the whole period of measurement. The inevitable error, which originated from the statistical function in observation with a counter of finite dimension and within a finite time, is estimated to be nearly ±2.6% of the total amount (±1.3 counts for total 50 counts) in our case. Further more, the time variation of the counts originating from cosmic rays is estimated at present to be much less than 1% of the cosmic ray intensity, especially for the hard component. Consequently, the observed change of gamma-ray intensity in our case should be mainly attributable to the intensity variation of soil radioactivity. The correlation between this intensity variation and the meteorological elements such as the amount of rainfall, variation of atmospheric pressure and temperature, is not yet

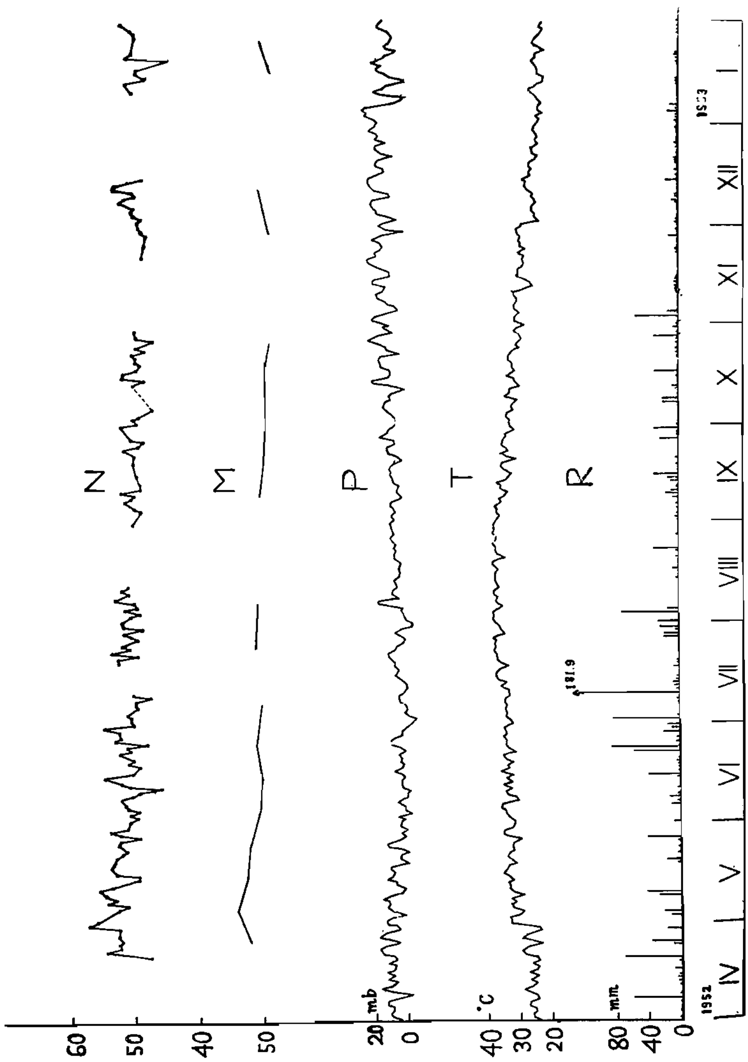

Fig. 3 Daily values of gramma-counting and meteorological elements. N: daily counts/min., M: ten days' mean counts/min., P: barometric pressure, T: atomospheric temperature, R: precipitation.

ascertained, and the interpretation of its nature awaits future research. Here it ought to be mentioned that it is very regretful that, due to a lack of measurement from July 11 to 20, 1952 during our absence from the Laboratory because of a survey tour, we can not discuss the intensity variation before and after the occurrence of the Yoshino Earthquake

Table 1.

	1952 April		May		June		July		August	
	Daily Mean	Ten Days' Mean	Daily Mean	Ten Days' Mean	Daily Mean	Ten Days' Mean	Daily Mean	Ten days' Mean	Daily Mean	Ten Days Man
1			57.0				54.3		51.2	
2			55.8		50.4		49.6		51.4	
3					49.3		50.0			
4					50.4		50.2		49.9	
5				53.9	49.0	50.3	50.6		48.5	
6			52.2		50.8			49.9	51.0	
7			50.8		51.8		49.1		49.1	50.4
8			54.2				49.3		49.5	
9			52.8		51.8		49.3		52.5	
10			54.4		49.8		46.9			
11					48.9		49.8		50.2	
12			55.3		45.3				51.3	
13			53.1		50.6				50.1	
14					51.8					
15			49.1	52.3		49. 9				
16			49.1		54.3					
17			52.7		49.8					
18										
19			53.5		48.7					
20			53.1		50.6					
21	47.4		52.8		49.8		52.0			
22			52.5				52.1			
23	54.3		51.6		51.8		48.9		49.7	
24	52.1		51.0		50.2		53.1			
25	52.3	51.8		51.7	50.7	50.8	50.1			
26	51.9		52.3		47.7		51.5	50.6		
27			52.0		52.6					
28	52.5		48.8		51.8		48.9			
29			51.9				49.9			
30	52.2		53.7		52.2		51.1			
31			50.8				48.1			

of July 18, 1952, whose epicenter, focal depth and seismic magnitude were at the point of 34°20′N and 135°40′E, 70 km deep and 7 in Pasadena scale. It was the only destructive earthquake near the Laboratory (100 km distant from the epicenter) during the whole period of measurement from April, 1952 to January 1953.

Table 1 (continued)

	September		October		November		December		1953 January	
	Daily Mean	Ten Days' Mean	Daily Mean	Ten Days' Mean	Daily Mean	Ten Days' Mean	Daily Mean	Ten Days' Mean	Daily Mean	Ten Days' Mean
1	49.3		51.4					48.3		
2			49.0				48.6			
3			49.3				48.0			
4			48.4	48.9			50.4			
5	48.2						51.2			
6	49.3		46.4				49.2			
7		49.9								
8	50.6						51.2			
9	49.9						5·04			
10	49.8						48.7		49.3	
11	51.3						49.3	49.8		
12	48.3						52.4			
13	48.3						52.0		50.3	
14			49.4						47.1	
15			47.5				47.6			47.9
16	49.0		50.9						48.7	
17			50.7						48.5	
18			48.8	49.2						
19										
20	49.4		48.1						43.5	
21		49.2	48.8		47.8				50.1	
22	49.2		48.9						49.4	
23			49.3							
24	51.0		47.5				54.6			
25	48.4		48.8		47.5					
26	47.9			48.2						49.6
27	49.6		46.1						48.8	
28			48.9		46.7				48.9	
29					48.1				49.3	
30			49.1							
31									50.9	

(B) Experimental Measurements on the Ground Surface

Various experimental measurements were made with the C_a-counter to determine the respective percentages of observed gamma-ray intensity originating from cosmic rays, and soil and air radioactivity, and moreover to observe the absorption of soil radioactivity by lead sheets. The reason for using the C_a-counter is that the Geiger tube in the C_b-counter is enclosed in the equipment itself while that of the C_a-counter on the contrary can be easily handled outside the equipment. The Geiger tube of the C_a-counter is made of a copper cylindrical tube of 0.8 mm-thickness, 18 mm-diameter and 106 mm-length, and its central line of tungsten of 0.1 mm-diameter is stretched in a mixed gas of Argon (12 mm Hg) and Ethylalcohol (3 mm Hg).

The experiments were made in October, 1952 directly on the ground surface outside our Institute, the ground being Alluvial sand. A lead block absorber, $5\times5\times10$cm, was used under varying circumstances. Thirty minute-countings were made; the experimental conditions and their mean values per minute (n) were as follows:

1. Case of unshielded Geiger tube put directly on the ground surface: $n=54.0$
2. Case of lateral and upper shielding with one layer of 5 cm-lead block: $n=34.5$
3. Case of base shielding with one layer of 5 cm-lead block: $n=37.1$
4. Case of the Geiger tube air-tightly enclosed in the lead cylinder of 10 cm-outer and 4 cm-inner diameters: $n=18.9$

The number of counts obtained by the measurement concerned is considered to be the sum of those originating from cosmic rays (soft and hard components), and gamma-rays from the ground and the atmosphere, disregarding for the moment the effect of contamination in the Geiger tube. While it was experimentally ascertained by V. F. Hess. [1953] that the effect of air radiation is negligible (less than one-thirtieth) compared with ground radiation, consequently in our case only the two effects (i.e., those of comic rays and ground radiation) need be treated. If C_h, C_s, G_h, G_s denote the counts per minute of the hard component (here the hard component means the ray penetrating a lead sheet of 3~5 cm thickness) and the soft component of the cosmic ray and ground radiation respectively, they are estimated from the above four experiments as follows:

$C_s \quad =19$ from the difference of the counts of Exper. (1) and (2)
$G_s \quad =17$ from the difference of the counts of Exper. (1) and (3)
$C_h+G_h=19$ from the counts of Exper. (4)

If there is, in this case, any experiment of counting on the water surface of considerable depth near the Laboratory, we can estimate the value of (C_h+C_s) and obtain each value of C_h and C_s respectively. Generally,

C_h is estimated to be nearly two or three times as much as the C_s on the ground surface, but in our experiment the value of C_s shows an extraordinarily large percentage in cosmic rays. Their origin is not clear but the fact that the experiment was made at a point on the ground surface 5 m distant from a brick building of 10 m height in our Institute is considered to be a possible source and the origin may be the effect of soft radiation from the brick building. At any rate, in our case, the counts originating from the hard component, the soft component and the ground radiation are, roughly speaking, one-third of the total observed counts respectively.

Next the experiment for absorption of ground radiation by the lead sheet was made at the same point above mentioned. The Geiger tube was placed at the height of some 10 cm above the ground surface, and the natural counts in the cases with and without a 5 cm thick lead-shielding over the counter were 48.4 and 34.0 per minute after a 30 minute-measurement, consequently in these cases the total counts and C_s are estimated to be 48 and 14 respectively. The reason for the decrease in counts for the total effect and C_s compared with the previous experiment exists in the points that the Geiger tube, in the present case, was placed 10 cm high instead of directly set on the ground surface and the shielding lead is placed only over the Geiger tube without the lateral shielding. And then the lead sheets of various thickness were inserted in the space between the Geiger tube and the ground surface. The corresponding counts for each thickness of the lead sheets are shown in Figure 4. It is to be remarked that the values of counts in Figure 4 are the sum of the cosmic hard component, a fraction of the cosmic soft component and the shielded ground radiation. From the experiment it could be deduced thah half of the ground radiation is absorbed by a lead sheet of 4 mm thickness, and that the rest decreases very slowly with the thickness-increase of shielding lead as seen in Figure. It is still in question as to whether there exists or not any penetrating component of ground radiation through a lead sheet of more than 3 cm thickness, and this

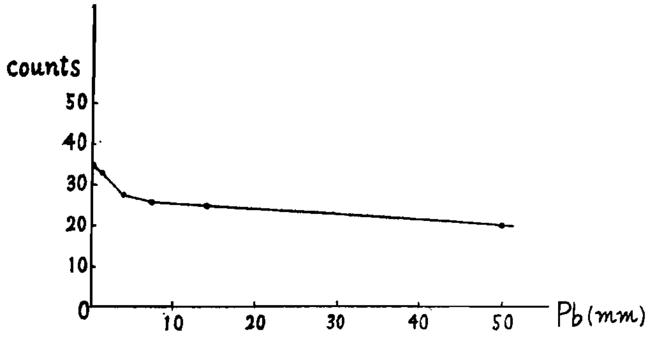

Fig. 4
Absorption of ground-radiation by lead-sheets.

problem will be discussed in the later paragraph.

(C) Measurement at the Deep Room Under the Ground surface

The observation for absorption of the hard component of cosmic radiation by the earth itself have been made by many researchers ~~in~~ in various countries. In our country an extensive observation of cosmic rays at the deep room of 3000 m H_2O in the Shimizu railway tunnel was made by Y. Nishina and Y. Miyazaki of the Scientific Research Institute of Japan during 1939 to 1945 and a part of the observation was reported by Y. Miyazaki [1949]. In our case the measurement of radioactivity at a deep underground room was intended to detect the locality of radioactivity in the deep adits of the mine and the time variation, if existing, of radioactivity under circumstances undisturbed by even the hard component of cosmic radiation. That is to say that even the effect of the hard cosmic ray is negligible compared with that of rock radioactivity at a depth of more than 100 m below the ground surface.

(1) Measurement at the Ikuno Copper Mine

The mountain rock of the Ikuno Copper Mine in Hyogo Prefecture is mainly Liparite. The measurement of radioactivity at various places in the adits were already made by T. Sadahiro [1951] and the local character of radioactivity at a great depth and the existance of some penetrating component of rock radiation were discussed in detail. For comparison the summary of his measurements will be cited here from his paper. The measurements were made with the C_a-counter under the condition of placing the Geiger tube at the center of the adit, its section being nearly 2×2 m square, and the Geiger tube being shielded by a square cylinder of brass of 1.5 mm thickness (P), by 8 lead blocks of $5 \times 5 \times 10$ cm (L_1) and by 24 lead blocks of $5 \times 5 \times 10$ cm (L_2) as shown in

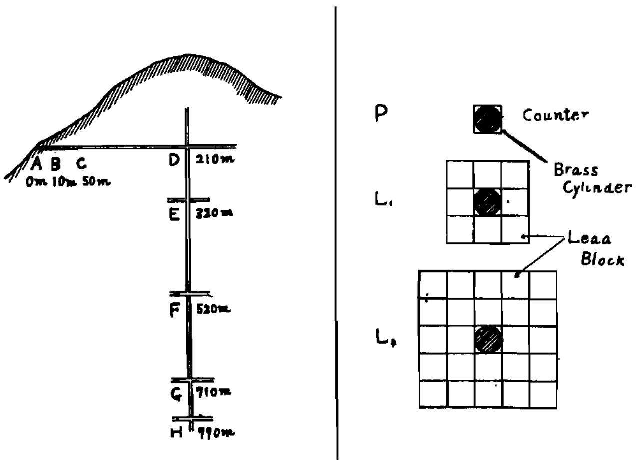

Fig. 5
Gamma-counting at Ikuno Mine by T. Sadahiro

Figure 5. The results obtained of each measurement at eight points are tabulated in table 2, the counts being the mean value per minute of 30-minutes measurement.

Table 2

Point	Depth (m)	P	P_1	L_1
A	0	37	23	—
B	10	46	21	11
C	50	40	18	10
D	210	30	11	6
E	320	26	12	—
F	520	27	11	7
G	710	60	30	17
H	790	37	15	8

The present measurement was made on August, 1952 after about two years later than the previous measurement by Sadahiro at the same points of the Ikuno Mine. The measurements were made with the C_a-counter at the two points of D (210 m-depth) and G (710 m-depth), and the mean value of 30 minutes measurement were as follows:

Point	Depth (m)	No Shielding, counts/min.	Shielding with lead cylinder of 3 cm-thickness, counts/min
D	210	45.0	6.9
G	710	80.2	12.2

Comparing the present measurement with the previous one, the values of P by Sadahiro is smaller than the present value and the values of L_1 are greater than those with the 3 cm-cylindrical shielding. The cause of of the small value for P is attributable to the shielding of brass square cylinder of 1.5 mm thickness for the soft component of rock radiation. And the cause of large value for L_1 is considered to be attributable to the effect of the oblique insident of the soft component of rock radiation, because the Geiger tube was open at its both ends for the oblique radiation in case of I_1 and the Geiger tube in the present case was hermetically sealed in the lead cylinder of 3 cm-thickness in each direction. In these measurements the following two points are worth mentioning: First, the measured count-value at point F is extraordinally large compared with the values at the other points. The rock surrounding point G is also Liparite and apparently not different from that at the other points, but the measurement of beta-ray made at the Radiation Laboratory of the Physical Institute of Kyoto University also showed a large value for the rock sample at point G compared with the other points. From this it is conluded that the rock at point G has an extremely large radioactivity compared with the rock at the other points, in spite of their apparently similar appearance. In the second place, it is remarkable that there exist some penetrating component of rock radiation which is not absorbed by the lead shielding of 3 cm-thickness. And it could not be attributable to the effects of contamination and other sources, because the counts of the penetrating component at point G (12.2 counts per minute) is also nearly twice that at point D (6.9 counts per minute) according to the same ratio of counts of unshielding at point G (80.2 counts per minute) to those taken at point D (45.0 counts per minute).

(2) Measurement at the Ogoya Copper Mine

The mountain rock of the Ogoya Copper Mine in Ishikawa Prefecture is mainly Tertiary tuff (mixture of green tuff and tuffaceous shale), and the measurement with the C_a-counter was made at ten points of various depth at various adits of the Ogoya Mine in November, 1952. The measured data during 30-minutes at each point is shown in Table 3.

Table 3

Point	Depth (m)	Co~~ntents~~unts in case of no shieling (per minute)	Counts in case of 3 cm lead shielding (per minute)
1	0	33.9	17.1
2	0	36.4	16.2
3	0	33.5	14.9
4	120	30.5	4.0
5	275	45.5	6.3
6	280	47.2	6.1
7	420	32.3	4.0
8	450	57.0	6.2
9	460	45.4	5.8
10	540	33.8	3.6

In the table, the counts taken with the 3 cm lead shielding at the three points, 1, 2 and 3, are mainly effected by the hard component of cosmic radiation, and the counts of the rest (4～10) are the effect of the penetrating csmponent of the tuff rock radiation. Here it was also observed that the counts given by the penetrating component of rock radiation at the points of large total counts, were slightly larger compared with those at the points of small total counts.

(D) Observation with the Lauritsen Electroscope

Various test measurements have been made with the Lauritsen electroscope (E_a) at the Laboratory and the underground room in the Ikuno

Copper Mine from December, 1950 to the present time. The instrument is primarily constructed for measuring the intensity of the radioactive isotope placed in the vessel underneath the quartz-fibre electroscope, but in our case it was reconstructed to fit the observation of the so-called "background" radioactivity at a deep underground room of high temperature and high humidity. The instrument thus reconstructed is an air-tight piece of equipment suitable for both visual reading and photographic registration. In Figure 6 the various measurements with the Lauritsen electroscope are plotted, the abscissa and the ordinate being the time in hours after the initial electric charge of the electroscope and the scale-division respectively. The sensitivity of the instrument is expressed, as already described, as the change of 1.64 scale-divisions per minute caused by gamma-ray ionization from R_a of 1 mc at a distance of 1 m, or in other words, as the change of 1.00 scale-divisions corresponding to the decrease of 1.0 electric volt of the electroscope's potential.

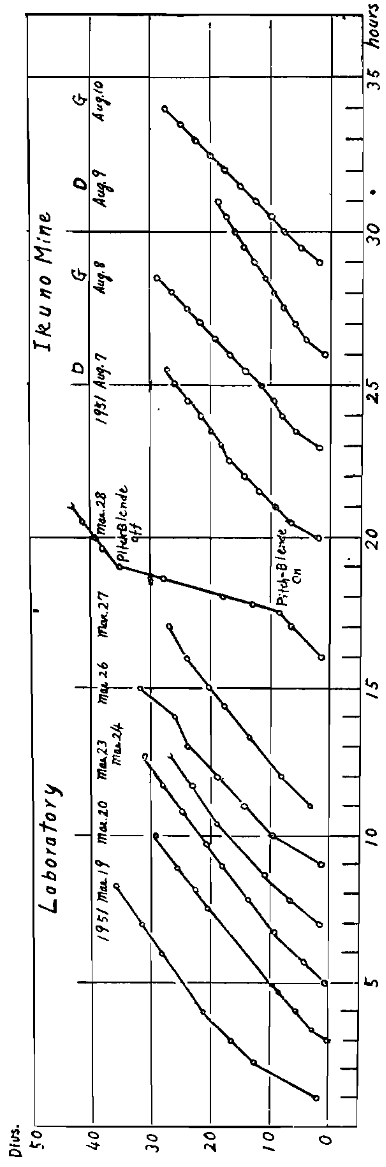

Fig. 6 Examples of decay-curve of Lauritsen Electroscpe observed at the Laboratory and Ikuno Mine.

Some points may be deduced from the various curves in Figure 6. The decreasing rate of deflection angle between two quartz-fibres of the electroscope caused by the initial electric charge is generally irregular for about 2-hours after the commencement of observation, but afterwards is nearly the same on any day at the same place. Minor fluctuations of the decreasing rate after the initial 2-hours on any day at the same place may be attributable partly to the change of ground radiation and partly to instrumental errors. On this problem, detailed research will be made by subsequent observations with a newly designed apparatus. It is to be remarked that the decreasing rate observed at the Laboratory, point *D*, and point *G* in the Ikuno Mine are roughly estimated to be 3.8-, 3.2- and 5.2-scale division per hour respectively and they correspond nearly to the gamma-ray counts of 50-, 45- and 80-counts per minute as measured at the respective places. From these it may safely be said that the various measurements of radioactivity made by us with both the Geiger counter and the Lauritsen electroscope may serve to some extent as a preparatory study of the nature of ground radiation.

In conclusion the radioactive measurements with the Geiger counter and the Lauritsen electroscope were made at various places on and below the ground surface. They are all preparatory measurements for a detailed study of minor fluctuation and secular variation, if existing, of ground radiation which may happen to be related to the occurrence of earthquakes, the volcanic eruptions, crustul deformation and other such natural phenomena. Making good use of these preparatory measurements, suitable equipment for the study of the changes of ground radiation has recently been designed and is in the process of manufacture, and a detailed report on this will be made in the near future. Among the results obtained from the present measurements, the following points are interesting and worth mentioning: There exists a considerable amount of penetrating component (3 cm-lead) of rock radiation at a deep place uninfluenced by the hard component of cosmic radiation. The ground radiation shows a minor fluctuation over a period of several days. The Geiger counter is usefull, in some cases, for detecting the slight differences of rock formation in mine-prospecting.

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